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(54) PARTICLE SENSING APPARATUS INCLUDING A DEVICE FOR ORIENTING GENERALLY FLAT PARTICLES

(71) We, COULTER ELECTRONICS INC., a Corporation organized under the laws of the State of Illinois, United States of America, of 590 West 20th Street, Hialeah, Florida, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

The present invention relates to particle sensing apparatus and more particularly to a device for orienting generally flat particles in a proper position as they pass sensing means.

The present invention provides particle sensing apparatus for sensing particles suspended in a sample fluid comprising a flow chamber for orienting sample particles having an entrance for receiving the sample fluid and an exit for fluid discharge, wherein said flow chamber is configured so that the ratio of a first dimension of the flow chamber to a second dimension of the flow chamber continuously increases in the direction of sample fluid flow, the first dimension being transverse to the second dimension, and the cross-section area of said flow chamber generally normal to the direction of fluid flow is configured to decrease gradually and continuously in the direction of fluid flow such that fluid flow within said flow chamber is caused to accelerate gradually and continuously, and means for sensing said sample particles in said flow chamber at a point prior to said exit.

In order that the invention may be clearly understood and readily carried into effect, apparatus in accordance therewith will now be described by way of example, with reference to the accompanying drawings, in which:

Figure 1 is a fragmentary medial sectional view of apparatus constructed in accordance with the invention;

Figure 2 is a top plan view of the apparatus shown in Figure 1;

Figures 3 and 4 are vectorial representations of the fluid velocity at different points in the apparatus of Figure 1;

Figure 5 is a sectional view taken along the line 5 — 5 of Figure 1 and in the direction indicated, showing a slit in the center area;

Figure 6 is a vectorial representation of the fluid velocity along the longitudinal axis of the apparatus of Figure 1 and parallel to the slit in Figure 5; and

Figure 7 is an enlarged fragmentary detail illustrating a portion of the apparatus shown in Figure 1.

Referring to Figure 1, the flow cell apparatus embodying the invention is designated generally by the reference numeral 10. Sample cells, such as squamous cells 12 carried in suspension are introduced from a suitable source through a sample tube 14 into a flow chamber 16.

The sample cells are generally flat and of so-called "fried-egg shape". The term "fried-egg shape" is used to describe squamous cells because such cells are generally circular in plan view and have a somewhat elevated nucleus which may or may not be centered.

The flow chamber 16 is defined by walls 17, as seen in Figure 2, and walls 18, seen in Figure 1. Walls 17 are parallel and straight whereas walls 18 follow exponentially narrowing curves. The walls 18 converge to an outlet 20 for fluid discharge.

The cells 12 are scanned by a light source 22 shown as providing a light in the flow chamber essentially transverse to the direction of flow of the sample particles 12. A photoresponsive means, such as a photocell 24, is positioned opposite the light source 22 to measure the amount of light passing through the flow chamber 16. The photocell 24, which can be a photomultiplier tube, provides a reading on

the amount of light transmitted. This measurement can be used to count the number of cells traversing the light beam and also can be used to measure other physical properties of the cells such as opacity and color. The photocell can also be used to measure the cross-sectional area of the sample cells. By varying the source of light or staining the sample cells, electroluminescence of the cells can be measured also to assist in identifying the type of cell present.

Referring again to Figure 1, a conduit 26 is connected to the flow chamber 16 for conducting fluid flow into the flow chamber. A laminar sheath flow designated by the arrows 28 is provided by sheath flow means 30 located in the bore of conduit 26. Sheath flow means 30 may comprise a plurality of tubes 32 extending through conduit 26 in the direction of fluid flow, as indicated, and surrounding the sample tube 14. The tubes 32 may function to prevent turbulent flow such that the fluid entering the flow chamber 16 is "collimated" and is non-turbulent. As the sheath fluid enters flow chamber 16, the fluid takes the form of a laminar sheath fluid flow. A more detailed discussion relevant to laminar flow will be made with reference to Figure 3.

Referring to Figures 1 and 2, cells 12 are shown being introduced to flow chamber 16 from the tube 14 in a random manner. As they enter the observing plane formed by light source 22 and photocell 24, the cells are shown lying in a plane that is transverse to a beam of light 33 from the light source 22. As can be seen in Figure 2, which would be the view as seen by the light source 22, each cell is oriented such that its flat side is facing the light beam, i.e., the maximum cross-sectional area of each particle in transverse to the light beam.

Digressing now to Figure 3, there is illustrated a vectorial representation of a fluid that exhibits laminar sheath flow as discussed previously. Such a laminar flow would be exhibited by fluid flow 28 as it enters the flow chamber 16. The horizontal arrows represent the vector velocities at the different locations across the conduit 26 comprising sheath flow in a parallel wall conduit, with the arrows being parallel, a typical one of which is designated 34. The locus of these vectors is a parabola as shown, the distance of any vector from a wall being typically as indicated at 35, this being the distance of the vector 34 from the wall. Once the laminar flow enters the flow chamber 16, vector flow as represented in Figure 4 would result. The fluid closest to walls 18 of flow chamber 16 have their velocities changed by the continuously changing width of walls 18. The velocity of the fluid within the flow chamber 16 now has a Y component of velocity imparted to it by the walls 18; the Y component of velocity decreasing in the fluid as the distance from the walls 18 increase until the velocity of the fluid in the center of fluid flow has approximately no Y component of velocity. In accordance with Bernoulli's principle, the fluid in the center of fluid flow in Figure 4 will have the greatest velocity and the pressure at the centre of fluid flow will be the least. Those cells located out of the center of fluid flow will have a Y component of fluid pressure acting on it to orient it towards the center of fluid flow.

When the sample fluid is introduced isokinetically into the centre of a laminar flow, similar to that shown in Figure 3, the center flow will remain in the center not crossing any planes of laminar flow. It should be understood that laminar flow can be approximated without the use of tubes 32 is a slow velocity fluid is introduced into a substantially infinitely long conduit prior to entering the flow chamber 16 of cell 10. The converging configuration of walls 18 of flow chamber 16 is such as to cause a constant acceleration of the flow of fluid toward outlet 20. The substantially infinite width of the cross section of the flow chamber near the sensing zone as compared to its height causes the flow of fluid to be not only laminar, but planar-laminar. The substantially infinite width is provided by a slit 36 centered on a longitudinal axis of least pressure and operates further to decrease the effect of a longitudinal wall on the fluid flow.

Referring to Figures 2 and 5, slit 36 can be seen extending along the full width of the flow chamber 16. The slit 36 extends in a direction which is approximately perpendicular to the plane of the light beam emanating from light source 22. This slit provides an enhanced axial plane of increased velocity which, by Bernoulli's principle, forms a plane of least pressure, thereby providing optimized particle orientation such that the particle assumes a position in which the flat side of the particle is transverse to the beam 33 from light source 22 of Figure 1. The axial region of least pressure that is formed by the slit 36 in the walls 17 of flow chamber 16 effectively provides a zero pressure gradient in a direction perpendicular from the axial center of fluid flow towards the walls 17. The walls formed by slit 36 are farthest from the axial center of fluid flow and have negligible effect upon the fluid flow. Figure 6 is a vectorial representation of the velocities in the flow chamber 16 of Figure 5 centered along the flow chamber longitudinal axis and parallel to slit 36 of Figure 5. As can be seen, the velocity along this region is approximately constant along

the length of slit 36 thereby representing a region of least pressure change, as described above.

It is believed that when a particle is in the flow chamber 16, the fluid in contact with the forward or leading edge of the particle will be moving faster than the fluid in contact with the back or trailing edge of the particle. This is believed to apply a tension on the particle which tends to align the particle in the direction of flow. In addition, any particle which is tilted to the direction of the fluid flow is turned by the component of fluid velocity perpendicular to the direction of flow at the center of the flow chamber since, it is believed, due to the decreasing spacing of the chamber walls 18, the inwardly directed velocity component of fluid flow which is greater downstream than upstream is produced perpendicular in the direction of fluid flow off axis. These perpendicular velocity compents are zero in the center of the flow chamber. The particles will then orient themselves along this axis of least pressure as described above wherein the plane formed by the maximum cross-sectional area of the flat-shaped particles will lie in a plane parallel to the axial plane of least pressure and orthogonal to beam 33 from light source 22.

The sectional view of Figure 5 shows the entrance to the flow chamber is constructed to form an elongated oblong configuration similar to that of the sample squamous cells that are to be scanned. The sample tube 14 is shown positioned in the center of the flow chamber 16 and axially centered within the chamber.

Sample squamous cells that are ejected from tube 14 into the flow chamber 16 will be on the center of the flow chamber as described above, the walls farthest away from the center providing a longitudinal axial region of least pressure. As stated above, it is believed that the fluid pressure increases as the distance from the axial center of flow increases thereby pushing cells that are tilted or not in the plane of symmetry towards the plane of symmetry due to the increase of pressure on points of the cells farthest from the plane of symmetry. Measurements are then made on the cells by projecting a cylindrical lens focused light beam 33 transverse to the direction of flow as shown in Figure 7. The light beam 33 intercepts the cells 12 at a point at which walls 18 are still tapering to orifice 20. When they reach the light beam, the "fried egg" shape squamous cells are oriented in the center of the flow stream in a longitudinal direction extending towards the axis of least pressure at approimately a right angle to beam 33. As a result, the maximum cross-sectional area of each cell is presented to beam 33. This provides the desired efficient results in measurements by slit-scan photometry heretofore not realized.

After emerging from exit port 20, the discharged stream may be deposited on a sheet for further individual particle investigation or routed through appropriate plumbing to waste or recycling means.

WHAT WE CLAIM IS:—

1. Particle sensing apparatus for sensing particles suspended in a sample fluid comprising a flow chamber for orienting sample particles having an entrance for receiving the sample fluid and an exit for fluid discharge, wherein said flow chamber is configured so that the ratio of a first dimension of the flow chamber to a second dimension of the flow chamber continuously increases in the direction of sample fluid flow, the first dimension being transverse to the second dimension, and the cross-sectional area of said flow chamber generally normal to the direction of fluid flow is configured to decrease gradually and continuously in the direction of fluid flow such that fluid flow within said flow chamber is caused to accelerate gradually and continuously, and means for sensing said sample particles in said flow chamber at a point prior to said exit.

2. Apparatus according to claim 1 wherein there is provided means for introducing the fluid suspension into the axial center of said flow chamber; said flow chamber having walls configured in the direction of fluid flow therethrough such that said fluid suspension is caused to accelerate gradually and continuously; said walls narrowing to form an exit for said fluid suspension located at a point approximately in the center of the fluid flow said sensing means being located in the vicinity of said exit.

3. Apparatus according to claim 1 or 2, wherein said entrance is opposite said exit and said exit has an elongated oblong configuration.

4. Apparatus according to any of claims 1 to 3, wherein said flow chamber includes a slit which locates a longitudinal plane thereof which provides a low pressure zone along said longitudinal plane.

5. Apparatus according to any of claims 2 to 4 wherein said walls taper exponentially in the direction of fluid suspension flow.

6. Apparatus according to claim 4 or 5 wherein said exit comprises said slit extending in a first direction across said entrance port and perpendicular to a second direction of said entrance port.

7. Apparatus according to any of claims 2 to 6 wherein said means for introducing said flow of sheath.

7. Apparatus according to any of claims 2 to 6 wherein said means for introducing said

fluid suspension includes: means for producing a flow of sheath fluid surrounding said sample fluid; and a sample tube extending into said flow chamber along said axial center.

8. Apparatus according to claim 7, wherein said means for producing said sheath fluid includes means for producing smooth, nonturbulent flow of the sheath fluid through said flow chamber, comprising a plurality of tubes extending in the direction of fluid flow such that said sheath is laminar within the entrance port of said flow chamber.

9. Apparatus as claimed in claim 7 or 8 wherein the entrance of said flow chamber is substantially centered in the sheath fluid flow.

10. Apparatus according to claim 1 wherein generally flat sample particles suspended in a sample fluid are injected through the sample flow tube into the centre of a flowing fluid which, if not planar laminar at the point of injection, becomes planar laminar shortly thereafter, said exit being opposite said entrance and in the configuration of a slit extending in a direction across the longitudinal plane of said flow chamber and perpendicular to the width of said entrance.

11. Apparatus according to any of claims 7 to 10, wherein said sample flow tube extends through the center of said entrance of said flow chamber.

12. Apparatus according to claim 1, wherein the flow chamber configuration along said first dimension axis is approximately constant.

13. Particle sensing apparatus substantially as described in the foregoing specification and illustrated in the accompanying drawings.

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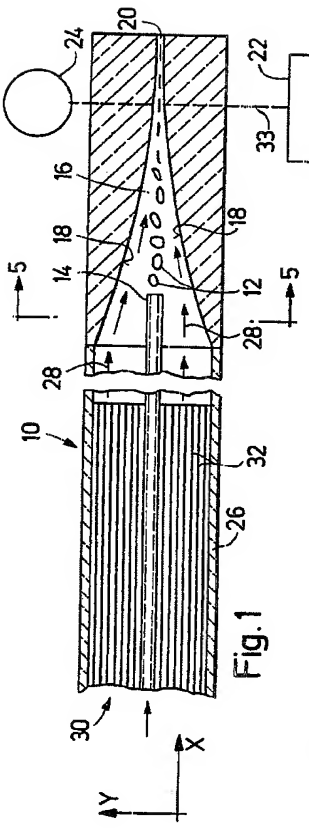

Fig. 1

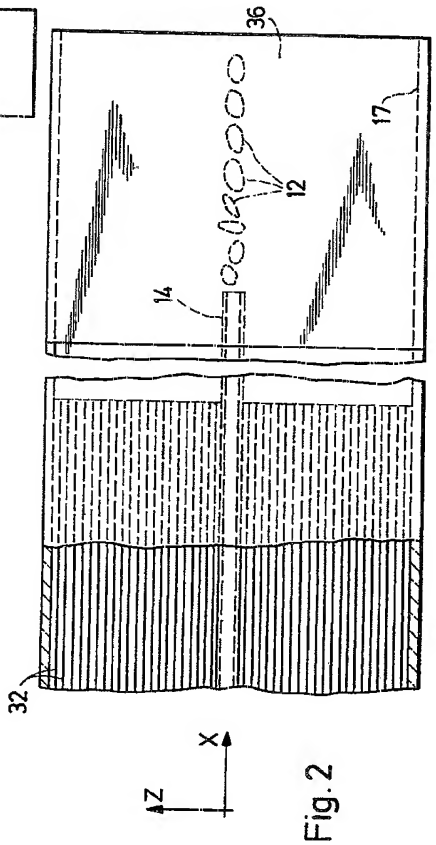

Fig. 2

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3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
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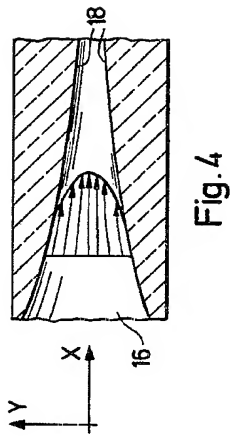

Fig.4

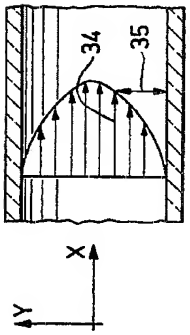

Fig.3

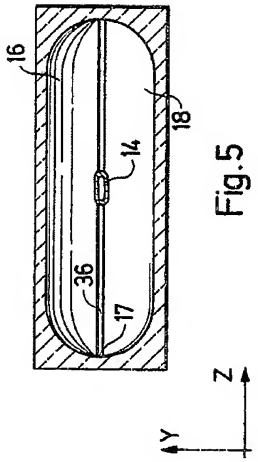

Fig.5

1471976 COMPLETE SPECIFICATION
3 SHEETS *This drawing is a reproduction of the Original on a reduced scale*
Sheet 3

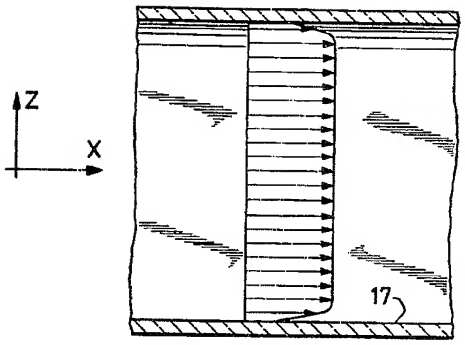

Fig.6

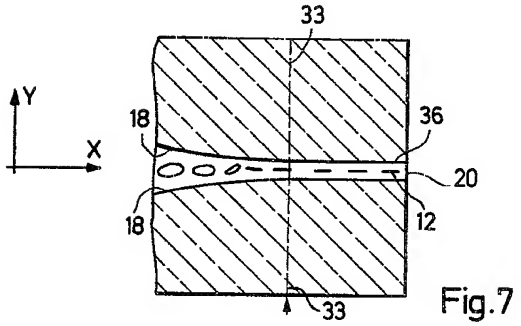

Fig.7